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Cognitive adaptations induced by a multi-language input in early development

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Children around the world successfully adapt to the specific requirements of their physical and social environment, and they readily acquire any language they are exposed to. Still, learning simultaneously two languages has been a continuous concern of parents, educators and scientists. While the focus has shifted from the possible costs to the possible advantages of bilingualism, the worries still linger that early bilingualism may cause delays and confusion. Here we adopt a less dichotomist view, by asking what specific adaptations might result from simultaneously learning two languages. We will discuss findings that point to a surprising plasticity of the cognitive system allowing young infants to cope with the bilingual input and reaching linguistic milestones at the same time as monolinguals.

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''When I was talking to my paternal grandmother I had to speak in a manner that I later discovered was called English, and when I was talking to my mother or her parents I had to talk a language that afterward turned out to be Spanish'' notes J.L. Borges [1]. In contemporary societies many children grow up in bilingual families and are faced with similar situations. Just like the young Borges they successfully learn to cope with different languages. Nowadays, in contrast to earlier views that bilingualism leads to language delays and confusion, it is widely believed that bilingualism has no such disadvantages; to the contrary, the focus has shifted to the positive effects of childhood bilingualism.

But how can the developing brain deal with the task of successfully acquiring two languages simultaneously? Simply switching attention from the possible disadvantages to the possible advantages will not allow us to better understand the processes triggered by the need to make sense of the bilingual language environment. Bilingual language acquisition is different from the monolingual one in many ways, however, it is unclear what cognitive adaptations may allow young children to cope with the challenge of acquiring two languages.

One possible way to conceptualize the changes induced by the bilingual environment would be to think of them analogously to other adaptations of the cognitive system. Consider for instance, classical visual adaptation studies [2], in which participants wear prism glasses that lead to an inversion of the left and right or up and down dimensions, and their adaptation to the new visual input is measured. Are there costs to such adaptation? There is certainly a 'learning period' where participants show a poor performance, followed by a 'consolidation period' in which the visual system shows adaptation to the new input. Analogously, one would expect that when exposed to two languages the developing brain would quickly adapt to processing two mutually exclusive language systems. Behavioral observations, according to which bilingual language acquisition follows the same milestones as the monolingual one despite the more complex input [3,4], point to such plasticity. However, the analogy between visual adaptation and a possible bilingual adaptation becomes problematic when one realizes that in contrast to a situation where the prism glasses are removed at the end of the study, bilingual individuals will likely continue using 'the prism glass of bilingualism' for the rest of their lives. Here we address the question what cognitive adaptations may occur in the cognitive system due to the early and continuous processing of two languages, by mainly focusing on the learning period and thus on young infants.

Importantly, besides having to extract patterns from a complex and variable dual language input, bilingual infants likely need yet another, possibly separate adaptation that allows them to flexibly switch attention between two languages systems, in order to be able to distinctively acquire both of them. To see why this is interesting, one would need to ask participants in the above-mentioned visual adaptation study to put on and off the prism glasses many times a day, and consequently to constantly switch between upright and upside down visual input. Likely, the cognitive system will optimize such switches, and minimize adaptation times. This should also be valid for

cases in which the language input contains frequent between-language switches. Bilingual adults change from one language to another rather smoothly and even young bilinguals must be able to successfully deal with these frequent switches.

In the following parts we will focus on two possible adaptations involved in dealing with a multilingual input. First, we will focus on changes that allow young infants learning different language systems simultaneously, and then on adaptations that may account for flexible language switching. We will discuss findings that point to a plasticity of the cognitive system that allows bilingual infants to cope with the linguistic input and to reach the linguistic milestones at the same time as monolinguals. We will argue that various results pointing to advantages or disadvantages in specific domains can all be seen as cognitive adaptations to the bilingual input (see Table 1). For instance, more fine tuned language discrimination abilities and better attention switching and memory may allow bilinguals to cope with the rapidly changing bilingual input, while a later sensitivity to matching minimally different word pairs to objects may be a signature of a broader category formation in bilinguals. Finally, we will discuss how these changes relate to a general plasticity of underlying brain networks, and whether such adaptations are specific to basic processes.

Adaptations stemming from processing a mixed language input

Whereas infants who have to acquire two languages simultaneously face an important challenge, they seem to pass language production milestones at an age similar to monolinguals [3,4], and display only minor differences in language processing [5,6]. Thus, the big puzzle becomes uncovering what mechanisms could infants exposed to two languages from birth (crib bilinguals) employ to efficiently deal with a linguistic signal coming from different languages.

A wealth of research suggests that infants can process various aspects of the languages they are exposed to from very early on. Bilingual and monolingual neonates can discriminate utterances from two languages of different rhythmic classes [7,8], and some months later they distinguish languages belonging to the same rhythmic class [9–11]. These studies suggest that well before infants start speaking, they have already acquired some of the crucial properties of their maternal language, and this is also the case for infants exposed to a bilingual language input. Indeed, bilingual infants can use the different prosodic cues to learn their two languages [12•]. However, the complex language input of bilinguals may require processes that are not required for monolingual language acquisition, resulting in possible changes in the involved processes.

One of the earliest differences observed between monolingual and bilingual infants comes from a study suggesting that while four-month-old monolinguals orient faster to the maternal language compared to a foreign language, bilinguals show the opposite pattern [5]. While it is unclear what such differences might mean, as it was expected that bilinguals orient faster to their two native languages, one could argue that such special attention to a foreign language may stem from an adaptation to a bilingual input that is often uneven (infants rarely hear two languages to the same extent). This would allow infants to focus more attentional resources to the weaker or less 'familiar' language, and thus learn it successfully.

This possibility is also supported by findings targeting visual language discrimination abilities. Infants do not only learn about the acoustic characteristics of their languages, but also about the visually co-occurring features of speech [13]. Research by Sebastián-Gallés *et al.* [14••] suggests that 8-month-old bilinguals, in contrast to monolinguals, can visually discriminate even two languages they are not familiar with. It was argued that such a bilingual advantage could not be due to perceptual

Table 1

Specific adaptations due to the bilingual environment

Study	Bilinguals' age	Main finding	Possible adaptive role
Bosch and Sebastian-Galles, 1997	4-month-olds	Faster orienting to a novel than to a familiar language	Greater attention fosters learning of novel languages
Sebastian-Galles *et al.*, 2012	8-month-olds	Better visual language discrimination of new languages	Better attention to co-occurring patterns in novel languages
Kovacs and Mehler, 2009a,b	7–12-month-olds	Better attention switching and simultaneous learning of two rules	Coping with a rapidly changing bilingual input
Fennell *et al.*, 2007	14–20-month-olds	Later matching of minimal word pairs to objects	Broader initial category formation
Poulin-Dubois *et al.*, 2013	18–24-month-olds	Smaller one language vocabulary	Bigger two language vocabulary
Byers-Heinlein and Werker, 2013	17–18-month-olds	Not obeying the Mutual Exclusivity principle in word learning	Learning multiple labels for the same object

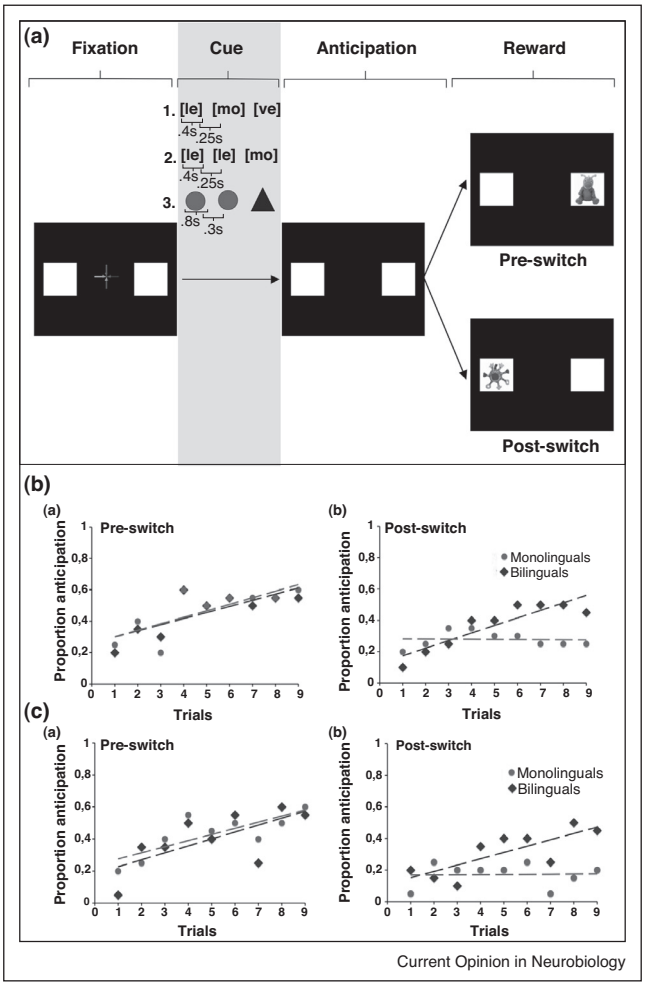
narrowing to the languages of exposure, but rather reflects an increased perceptual attentiveness to visual language-related cues for unfamiliar languages. Such findings are in line with the earlier described possibility, according to which a greater attention to non-familiar languages leads to better discrimination and possibly an efficient learning of a language from which they receive a scarcer input (see Table 1). Alternatively, such differences might be explained by the richness of the bilingual input which likely fine-tunes infants' discrimination abilities, as a more general adaptation.

While the above two studies describe differences between monolinguals and bilinguals that can be seen in terms of enhanced processing, other studies have found poorer performance in bilingual infants in specific tasks [6] and lower vocabularies [15]. Could such possible 'costs' of bilingualism also have an adaptive role? In the study by Fennell *et al.* [6] bilingual infants learned word-object associations with non-words that were minimal pairs (e.g., bih/dih) only at 20 months, lagging behind monolinguals with about 3 months. However, they succeeded at the same time as monolinguals with words that were not minimal pairs (e.g., lif/neem)[16]. One could argue that a later emerging sensitivity to minimal pairs in learning word/object associations might be explained by a flexibility of bilinguals in forming broader phonological categories. In line with an earlier proposal, these results may reflect an adaptive strategy to learn two languages [17]. In a similar vain, a lower vocabulary observed in bilingual children when one of their languages is measured [15,3] may be explained with a possible adaptation that ensures a 'fair' division of the possibly limited cognitive resources between the two languages. Interestingly, however, when bilinguals' vocabulary is measured taking together both languages, their cumulative scores are equal or higher than that of monolinguals, pointing to a possibly more general memory enhancement. Relatedly, studies have found that bilingual, but not monolingual 18-month-olds showed generalization in a deferred imitation task [18••], suggesting an advantage in memory generalization for bilinguals.

Adaptations stemming from continuous attention switching between two languages

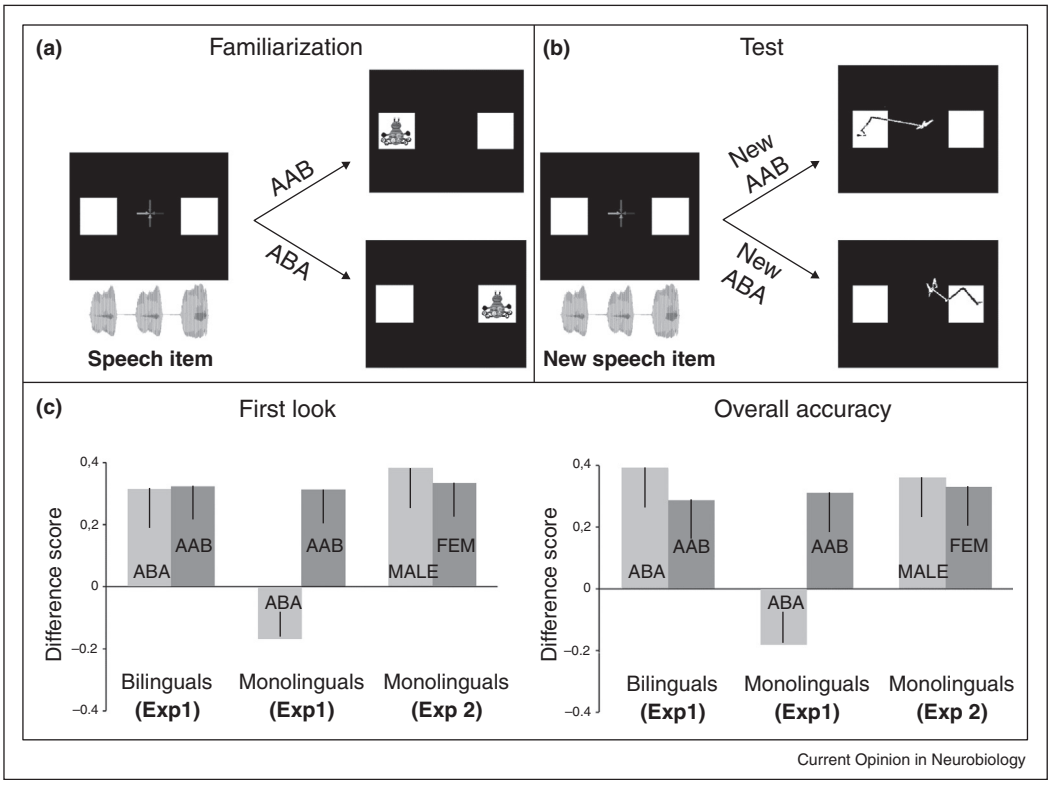
The frequent switching of attention between two languages may result in further changes in the cognitive system. Studies have found that selecting a language in bilingual production leads to advantages in performing tasks that require executive functions (EF) in adults [19,20], preschool-aged children [21] and even in toddlers [22]. However, such differences are not consistently found [23,24], and it is unclear what factors may modulate the effects of language switching in production on EF. Nevertheless, one could argue that the greatest challenge for the cognitive system is not to switch between two languages once they were acquired, but to separate them during learning. Possibly, the continuous monitoring of the bilingual input results in an early boost of attentional control already in infancy. In a series of eye-tracking studies we asked whether such enhancements might arise in crib bilinguals prior to language production [25,26]. In Kovács and Mehler [25] we tested monolingual and bilingual 7-month-olds on a response-switching task where a previously valid and repeated response in the pre-switch phase (e.g., an eye movement to the right side of the screen after a cue) has to be inhibited to perform a new response in the post-switch phase (e.g., an eye movement to the left). While both groups learned to correctly anticipate the reward in the pre-switch phase, only bilingual infants showed learning in the post-switch phase (Figure 1b after

Figure 1



Inhibiting a previously learned response in 7-month-old monolinguals and bilinguals. **(a)** Trial structure in the study of Kovács and Mehler [25]. After a linguistic or visual cue a visual reward followed in one of the two white squares (pre-switch phase-nine trials). In the post-switch phase the rewards appeared in the other square (nine trials). We measured infants' anticipatory looks before the appearance of the reward. **(b,c)** Results of Experiments 2 (linguistic cues) and 3 (visual cues). Proportion of infants with correct anticipatory looks.*Source*: Adapted from *PNAS*, vol. 106.

Figure 2



(a) Familiarization phase of Experiment 1 from Kovács and Mehler [26]. Infants heard words having different structures: AAB or ABA, that is words with repeated first and second, or first and third syllables. Each structure was paired with rewards on one or the other side, respectively. **(b)** Test phase of Experiment 1 where infants heard new words following one of the structures and no reward was displayed. We measured where infants anticipated the reward. On the right, two scan paths of an infant are depicted on two trials. **(c)** Measures of learning for the two structures or the two voice cues. Left: Difference scores for first looks [(number of correct − incorrect looks)/(number of correct + incorrect looks)] related to chance (Experiment 1); and for male and female voices (Experiment 2-Control). Right: Difference scores for overall accuracy. Error bars represent SE. *Source*: Reprinted from *Science*, vol. 325.

[25]). This points to better-developed EF abilities that may help bilinguals to successfully monitor and keep separate the linguistic representations of the two languages, and allow them to efficiently acquire each language.

In a different set of studies [26], we explored whether such changes in EF abilities result in a more successful monitoring of regularities that come from two language-like systems. Specifically, we asked how monolingual and bilingual infants learn and generalize repetition-based regularities implemented in speech-like stimuli when they are exposed to two structures simultaneously. The data suggests that 12-month-old bilinguals are more efficient in learning two regularities simultaneously than their monolingual peers. In a situation where infants had the opportunity to learn two mutually inconsistent regularities, bilinguals learned both, while monolingual infants learned only one of them (see Exp. 1, Figure 2). However, monolinguals were successful in learning two associations that were not based on regularities but rather on surface features of the stimuli (male female voice-Exp. 2-Control).

Using electrophysiological measurements, Kuipers and Thierry [27] investigated whether monolingual and bilingual toddlers differ in their semantic processing efficiency and their allocation of attention to expected and unexpected visual stimuli. Although ERP effects elicited by semantic relatedness were similar in the two groups, pictures unrelated to the preceding word evoked greater pupil dilation than related pictures in bilinguals (linked to a decrease in N400), but not in monolinguals. The authors have argued that attention to unexpected stimuli seems to facilitate semantic integration in bilinguals, suggesting that bilingual toddlers are more tolerant to variation in word-referent mappings [28].

These studies targeted the question of how different processes interact in the service of language acquisition, and how these are shaped by early bilingual exposure.

According to the findings, bilingual language learning seems to involve domain-general executive function (EF) abilities, even at an age when infants do not yet produce words. Improved EF will, in turn, be used to deal more efficiently with conflicting linguistic representations and possibly also with non-linguistic ones. Alternatively, such effects might reflect more general changes, specifically a better coping with a rapidly changing and highly variable environment (see Table 1).

Different principles and different heuristics?

Bilingualism seems to result in specific changes in some basic cognitive mechanisms (memory, EF, perceptual discrimination) in early infancy and it is related to structural and functional changes in the underlying brain networks in adults [29–31, see 32• for a review]. However, early bilingual exposure likely does not affect the cognitive system as a whole. The current evidence targeting young infants is mixed, while some studies found no differences in how bilingual and monolingual infants process their visual environments [33], other studies involving large groups of monolingual and bilingual infants find fine tuned differences in visual habituation patterns [34].

Furthermore, besides a general plasticity and specific changes in core mechanisms, importantly, early bilingualism could induce modifications in complex heuristics as well. One candidate for such adaptation could be, for instance, the word-learning heuristics infants may use. Early work targeting monolinguals suggests that infants use specific disambiguation strategies to identify referents for words. For instance, if they encounter a new label (e.g., dax) together with a familiar object for which they already have a lexical referent (e.g., shoe) and a new object, they will infer that the new word's referent must be the new object. This is also referred to as the Mutual Exclusivity principle, according to which infants assume that one object has only one label [35]. While monolingual infants can successfully use Mutual Exclusivity to learn new labels for new referents, infants exposed to bilingual or multilingual input are often exposed to lexical equivalents in the two languages. Thus, in their case, the 'one object — one label' strategy does not seem to be easily applicable. Experimental data suggest that multilingual children seem to apply the principle of Mutual Exclusivity less than monolingual children, by often displaying chance performance [36,37••,38]. However, it is unclear whether this chance performance reflects an adaptation, which allows them to accept that an object can have multiple verbal referents. Recent studies provide more direct evidence in this direction, suggesting that infants exposed to multiple languages adopt different strategies and accept that one object can have multiple referents more frequently than monolinguals in a synonym task [Kovács, unpublished].

A further domain where differences were observed between monolinguals and bilinguals is in reasoning about other people's beliefs and intentions. While bilingual children and adults seem to outperform monolinguals in tasks involving belief reasoning [39–41] it is unclear whether this reflects a genuine advantage in inferring others' mental states, or an EF advantage in sustaining a mental state representation that conflicts with one's own. Recent studies suggest that bilingual children display advantages on tasks that require spatial perspective taking [42] or interpreting a speaker's intended meaning [43]. Fan *et al.* [43] has found that children exposed to a second language outperformed monolinguals in a task where they had to take another person's perspective in order to interpret the speaker's meaning, a difference that was not related to children's EF abilities.

In conclusion, the studies discussed here suggest that exposure to two languages leads to specific changes in the cognitive system, which will change, in turn, how language is acquired, and might possibly also change the developmental trajectories of specific abilities in other domains. However, such early adaptations presumably do not imply that bilingualism leads to radical representational changes in the human mind. Instead, they indicate that the cognitive system of a young child is ready to successfully deal with the challenge coming from multiple languages and exposure to two languages from birth results in specific processing changes from the very early stages of development.

Conflict of interest statement

Nothing declared.

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The study presents striking findings according to which 8-month-old bilingual infants, in contrast to monolinguals, are able to visually discriminate two languages they are not familiar with. It was argued that such a bilingual advantage could not be due to perceptual narrowing to the languages of exposure, instead reflecting an increased perceptual attentiveness to visual language-related cues for unfamiliar languages.

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